ELECTRIC MELTING OF COPPER AND BRASS

C. A. HANSEN

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Dr. W. R. Whitney has turned over to me a request from the American Institute of Metals for a paper on the above subject, one that I hesitate to write upon since I have had but very little experience with copper and its alloys in any type of furnace. Mr. W. G. Rothwell, Superintendent of our Schenectady Works Brass Foundry, who yearly turns out from 3,000,000 to 4,000,000 lbs. of castings, and Mr. L. G. Cooper, our Fuel Engineer, have, however, supplied me with considerable information concerning the more commonly used melting methods, the publication of which will undoubtedly interest many.

The general purpose of this paper, then, will be to summarize theoretical requirements, results obtained under ordinary and extraordinary conditions in furnaces of the Rockwell, Charlier and Schwartz types; results obtained in a few experiments with an electric furnace; and a comparison and discussion of the results. In this discussion I shall try to confine myself to the few things I feel more or less competent to discuss.

THERMAL DATA.

Specific heats—Calories per gram per degree Centigrade.

Copper at..........	0°C	0.0939	Richards[1]
Copper at..........	300°C	0.09846	Naccari[1]
Copper at..........	900°C	0.1259	Richards[1]
Copper from........	0°C to 300°C	0.104	LeVerrier[2]
Copper from........	20°C to 1300°C	0.110	Assumed
Zinc from..........	300°C to 500°C	0.122	LeVerrier[2]
Zinc from..........	20°C to 1100°C	0.130	Assumed

Melting Points.

Copper .... 1084°C
Zinc .... 419°C
Brasses—
     90 Copper 10 Zinc................. 1040°C   Shepherd[3]
     80 Copper 20 Zinc................. 1000°C   Shepherd[3]
     70 Copper 30 Zinc................. 940°C   Shepherd[3]
     60 Copper 40 Zinc................. 880°C   Shepherd[3]
     50 Copper 50 Zinc................. 860°C   Shepherd[3]

Heats of Fusion—Calories per gram.

Copper 43   Richards[1]
Zinc .... 28.13   Persons[2]

Heat of Solution—Zinc in copper—Calories per gram alloy.
32% copper—68% zinc .... 52.5   Baker[4]

Baker found that the above ratio—$CuZn_2$—evolved more heat than any other combination and found a possible sub-maximum corresponding to CuZn. I shall assume that all of the zinc in the brass melted combines with copper in the ratio $CuZn_2$.

Vapor Pressures.

Copper at........ 1700°C— 0.002 atmospheres   Greenwood[5]
Copper at........ 1900°C— 0.009 atmospheres   Greenwood[5]
Copper at........ 2100°C— 0.022 atmospheres   Greenwood[5]
Zinc at.......... 900°C— 0.732 atmospheres   Barus
Zinc at.......... 1000°C— 2.5   atmospheres   Greenwood
Zinc at.......... 1100°C— 6   atmospheres   Greenwood
Zinc at.......... 1200°C—12   atmospheres   Greenwood
Brass—
    76 copper—24 zinc 1000°C±15°—0.29 atmospheres Hansen[6]
    76 copper—24 zinc 1084°C±15°—0.66 atmospheres Hansen[6]
    76 copper—24 zinc 1150°C±15°—1.18 atmospheres Hansen[6]
    55 copper—45 zinc 900°C±15°—0.24 atmospheres Hansen[6]
    55 copper—45 zinc 950°C±15°—0.44 atmospheres Hansen[6]
    55 copper—45 zinc 1000°C±15°—0.72 atmospheres Hansen[6]
    55 copper—45 zinc 1100°C±15°—1.55 atmospheres Hansen[6]

[1]Landoldt und Börnstein—Physikalische Tabellen.
[2]Chemiker Kalender, 1905.
[3]Jour. Phys. Chem., 8-421-1904—Approximated from Shepherd's curve.
[4]Proc. Royal Soc., 68-9-1901.
[5]Trans. Faraday Soc., 1911.
[6]Boiling points in Arsem Vacuum Furnace in Hydrogen atmosphere (not pub-lished.) From these boiling points, the calculated heat of solution of a gram equivalent of zinc in copper is
   (a) 5400 calories for 24% Zn alloy.
   (b) 2500 calories for 45% Zn alloy.
Baker's value for 68% alloy was 5040 calories.

Heating Materials Used in This Paper.

Texas crude oil—7.25 lbs. per gallon.
Heat value—19,000 B. T. U. per lb.
Heat value—34,700,000 calories per gallon.
1 kilowatt hour—850,000 calories.

Thermal Calculations.

Heat required to bring 100 lbs. copper to 1300°C pouring temperature.

Heating	6,290,000	calories
Melting	1,950,000	calories
Total	8,240,000	calories

Heat required to bring 100 lbs., 80 copper, 20 zinc brass to pouring temperature of 1100°C.

Heating Copper	4,310,000	calories
Melting Copper	1,560,000	calories
Heating Zinc	1,270,000	calories
Melting Zinc	255,000	calories
	7,395,000	calories
Less heat of solution of Zn	476,000	calories
Total	6,919,000	calories

Theoretical Requirements.

To bring 100 lbs. copper to 1300°C........ 0.237 gallons oil
To bring 100 lbs. copper to 1300°C......... 9.70 Kw. hours
To bring 100 lbs. 80:20 brass to 1100°C.... 0.199 gallons oil
To bring 100 lbs. 80:25 brass to 1100°C.... 8.13 Kw. hours

Oil Fired Furnaces.

Strictly comparative tests were made on Schwartz, Rockwell and Charlier furnaces in which particular care was taken to get the best results out of each furnace as regards metal recovery and fuel consumption.

Typical Mixture Melted.

200 lbs. Copper scrap.
200 lbs. Copper turnings
200 lbs. Brass turnings
300 lbs. Brass gates
8 lbs. Tin
12 lbs. Lead
80 lbs. Zinc

1000 lbs. Total.

Typical Analysis of Metal Poured.

Copper 80.7%
Zinc 16.4%
Lead 1.2%
Tin 1.7%
Iron ....trace

Results Obtained Under Strict Test Conditions of Operation.

Furnace	A	B	C
Number of heats poured............	5	8	....
Average weight charge, lbs............	1000	700	....
Average time per heat minutes........	113	64	....
Total Metal charged, lbs.............	5000	5650	....
Total Metal recovered, lbs............	4886	5540	....
Total Metal loss, lbs.................	114	110	....
Per cent. Metal loss.................	2.28	1.81	....
Total lbs. fuel oil used..............	765	760	....
Gallons oil per C lbs. metal..........	2.02	1.78	....

Similar results not obtained under strictly test conditions but under conditions of ordinary practice were as follows:

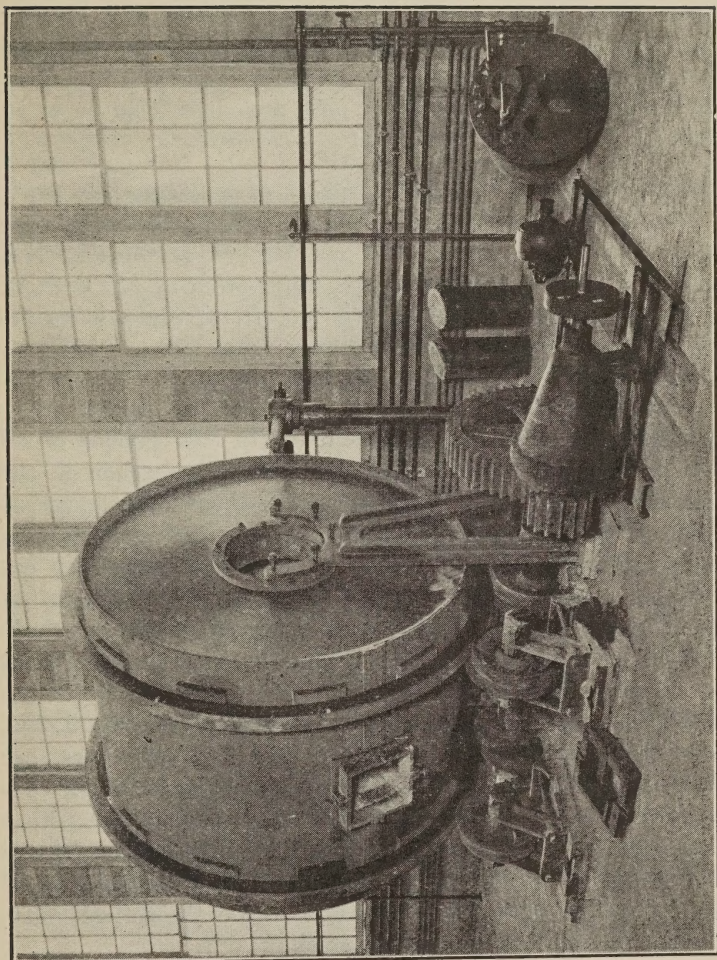| Furnace	A	B	C
Number of heats poured............	17	6	6
Average weight charge.............	1000	750	750
Average time per heat minutes........	88	71	85
Total Metal charged, lbs.............	17009	4487	4500
Total Metal recovered, lbs............	16020	4371	4364
Total Metal loss, lbs.................	989	116	136
Per cent. Metal loss.................	5.82	2.5	3.02
Total lbs. fuel oil used..............	4216	682	696
Gallons oil per C lbs. metal..........	3.46	1.97	2.00

FIG. 1.   Week's Rotary Arc Furnace in Course of Erection.

Concerning B Furnace—the cost of lining is about $14.00, of which $10.00 is labor. Special Munroe fire brick shapes are used and the life of a lining averages slightly more than 1000 heats, making this item about 2/10 cents per 100 lbs. metal melted. One man looks after each furnace and, beyond a few minutes spent each morning punching tuyeres and claying up pitts in the lining, his attention is given wholly to the metal he is melting. All of the copper alloys are poured into heated graphite crucibles and the 70-lb. pots used last from 60 to 70 pours at 200 lbs. metal each pour.

Blast is furnished to seven furnaces of an aggregate capacity of 6,000 lbs. metal by means of a positive pressure blower having a displacement of 19.6 cu. ft. per revolution, and driven by a 35 H.P. motor at an average speed of 140 R. P. M. The displacement is therefore 2740 cu. ft. of air per minute at atmospheric pressure and the blast pressure is limited to 16 oz. per sq. in. by suitable valves and by-pass.

Theoretically, a 750 lb. heat melted with 2.00 gallons of oil per 100 lbs. metal requires 1240 lbs. air if the carbon in the oil is burned to carbon monoxide and about half again as much if burned to carbon dioxide. The former condition is probably the one which interests us, since too strenuous endeavors to economize oil would only lead to the substitution of zinc for oil as fuel, and zinc is still the more expensive. It requires energy to compress this air to the average value used of 14 oz. pressure and this energy is just as much a part of the fuel bill as the oil. Theoretically it amounts to 0.825 Kw. hrs. per 750 lbs. heat, or more correctly 0.055 Kw. hrs. per gallon of oil burned. Practically, since the blower is run constantly and the air is by-passed when the furnaces cease taking it, some 15 Kw. is expended during 10 hrs. each day for the melting of some 20,000 lbs. of metal, i.e., for the burning of some 450 gallons of oil and, instead of the theoretical 0.055, we have 0.33 Kw. hrs. per gallon of oil.

Summarizing the results and comparing them with the theoretical requirements for the 80:20 brass, which we assume is the equivalent of the alloy made, we get that much abused and generally useless term—thermal efficiency.

Oil Fired Furnaces Melting 80% Copper-Brass.

Furnace	Test Conditions			Ordinary Practice		
	A	B	C	A	B	C
Gal. oil per C lbs. metal...	2.02	1.78	....	3.46	1.97	2.00
Kw. hrs. blast per C lbs. metal	0.67	.59	....	1.14	0.65	0.66
Oil equiv. of blast Kw. hrs. gals..............	0.016	.014	....	0.028	0.016	0.016
Total oil or equivalent..	2.036	1.794	....	3.488	1.986	2.016
Theoretical requirements.						
Gallons oil per C lbs.....	0.199	0.199	....	0.199	0.199	0.199
Thermal efficiency %.....	9.77	11.08	....	5.70	10.00	9.87

Furnace A was lined with a clay bonded carborundum which at least partially explains the decided difference from the others in thermal efficiency. In the above the blast power required is converted to oil equivalent on the basis of 40.7 Kw. hrs. per gallon of oil, i. e., on the basis of perfect interchangeability of theoretical heat values and not on the basis of the actual amount of electrical energy that can be obtained from a gallon of oil with any known engine system. With the modern oil engine 12.75 Kw. hrs. per gallon of similar oil represents excellent practice.

The electric furnace experiments were conducted on copper, and for the sake of comparison the following oil furnace results are approximated by using the comparative theoretical requirements for brass and copper and by assuming the same furnace efficiency. The latter assumption favors the furnace since the higher temperatures used in melting copper will most certainly entail decreased thermal efficiency.

Oil Fired Furnaces Melting Pure Copper.

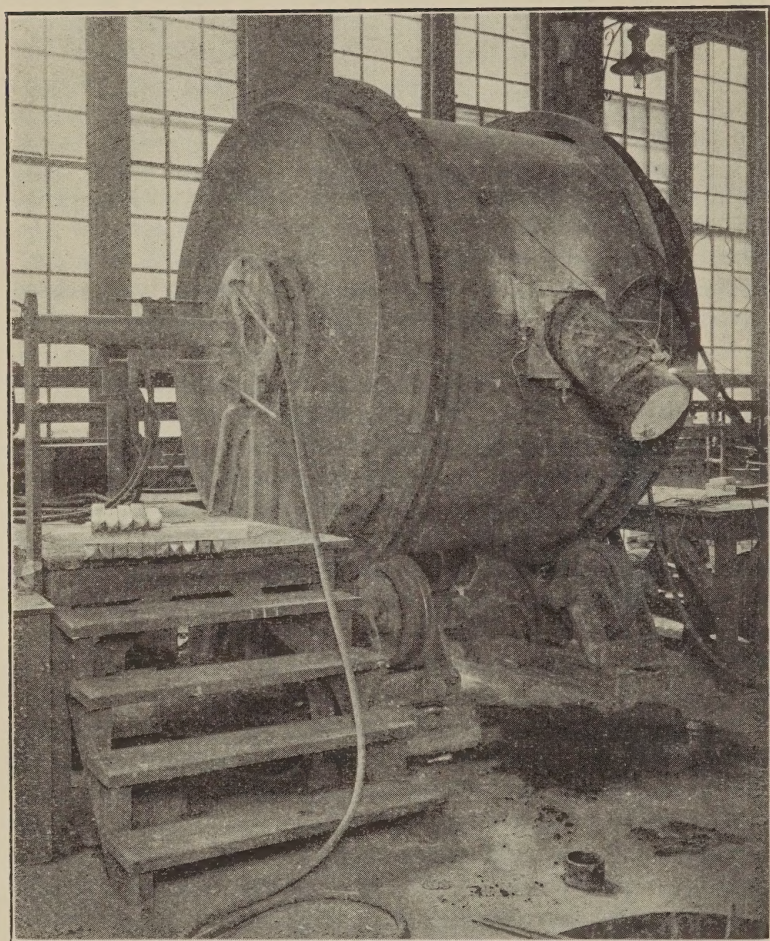| Furnace	Test Conditions			Ordinary Practice		
	A	B	C	A	B	C
Efficiency %............	9.77	11.08	....	5.70	10.00	9.87

FIG. 2.   Week's Rotary Arc Furnace.

Theoretical requirements.

Gals. oil per 100 lbs. cop-
per ....0.237   0.237 ... 0.237   0.237 0.237

Actual gals. oil per 100
lbs. copper ....2.43   2.14   ... 4.07   2.37   2.40

Note—The gallon of oil is used instead of the calorie or the B.T.U. simply be-
cause it is a more concrete unit to those outside the laboratory. The 100 lb.
metal unit is chosen since it is quite general for cost sheets, etc., to be made
up on this basis.

Electric Melting of Copper.

The furnace used was one designed and built by Mr. C. A.
Weeks of Philadelphia, primarily for the distillation of zinc,
and it was set up and tested for him in our laboratory in the
winter of 1909-1910. Figures 1 and 2 give a good idea of its
general appearance. It consisted of a horizontal, cylindrical
drum, 8 ft. in diameter by 6 ft., lined for the copper melting
tests with a 9 in. course of Munroe brick and a 2 in. layer of
Dixon's clay graphite mixture. The drum was mounted on
rollers which could be motor driven through an appropriate
gear reduction. Stationary heads, water cooled, concentric
with the furnace axis served to pass 6″ diameter graphite
electrodes into the furnace interior. The heat was supplied
by radiation from an arc and the rotation of the furnace body
was intended to equalize temperature of the furnace lining
by periodically bringing all parts of it in contact with the
charge. Incidentally, thorough mixing of the charge would
be secured by this rotation. The copper melting experiments
were of purely secondary consideration to Mr. Weeks and
both the furnace and results obtained would be very materially
improved if the design were made with special reference to
convenience in melting copper and its alloys.

The results obtained were as follows:

a. Furnace at room temperature at start.
2,000 lbs. copper scrap charged.
1,926 lbs. copper ingots recovered.
74 lbs. or 3.7% not accounted for.
Time required, 3 hrs. 50 min.

Voltage 110, 40 cycle.

Current, 2,100 amperes.

Power used, 630 Kw. hrs.

b. Furnace at room temperature at start.

No copper charged.

Furnace interior heated to 1350°C.

Time required, 3 hrs.

Power used, 512 Kw. hrs.

The furnace requires 36 hrs., at an inside wall temperature of 1300°C. (zinc experiments), for the outside surface to reach constant temperature on account of the great heat storage capacity of the lining material so it is not true that the difference in power consumptions for the two experiments above detailed will give directly the amount necessary for melting the copper. It will be seen that this difference is less than is theoretically necessary to melt copper. It follows, however, that if the furnace were operated continuously the amount of energy required per heat would approach closer and closer to that difference during the first 36 hours.

There are two ways of getting at the amount of power required to melt copper after the furnace has been warmed up both of which will be given.

After the furnace had been in operation 36 hrs. with an inside temperature of 1300°C, the total loss of energy from the furnace was 70 Kw.—this including direct electrical losses in apparatus, losses in cooling water and losses from the furnace shell. 200 Kw. can be supplied to the furnace on a two ton charge of copper without seriously overheating the lining, hence an efficiency of (200—70)÷200 or 65% can be assigned by this method. At this efficiency it would require 298 Kw. hrs. per ton of copper or 14.9 Kw. hrs. per 100 lbs. as against the 9.70 Kw. hrs. theoretically necessary.

The other method of getting at the same result is by analogy to results obtained in a steel melting furnace where the opportunities for heat loss were very similar in all respects to the

opportunities for heat loss in the copper melting furnace. In the latter furnace the following results—each figure the result of averaging many figures—have been obtained. The steel furnace had a nominal capacity of two tons as did the copper melting furnace.

STEEL FURNACE.

Cold Furnace and Cold Scrap Charge.

1 ton charge melted, 1,480 Kw. hrs. per ton.......... 100 %
2 tons charge melted, 980 Kw. hrs. per ton.......... 66.2%

Hot Furnace and Cold Scrap Charge.

1 ton charge melted, 782 Kw. hrs. per ton............ 52.9%
2 tons charge melted, 570 Kw. hrs. per ton............ 38.5%

COPPER FURNACE.

Cold Furnace and Cold Scrap Charge.

1 ton charge melted, 630 Kw. hrs. per ton........... 100 %
Above value determined experimentally.

By analogy to steel furnace results:
2 tons charge melted, 417 Kw. hrs. per ton........... 66.2%

Hot Furnace and Cold Charge.

1 ton charge melted, 333 Kw. hrs. per ton........... 52.9%
2 ton charge melted, 243 Kw. hrs. per ton........... 38.5%

The two methods of reasoning lead then to 298 Kw. hrs. and to 243 Kw. hrs. per ton of copper or efficiencies of 65% and 80% respectively, an agreement that is fairly satisfactory considering the slight amount of data available.

The analogy between steel furnace and copper furnace can perhaps be carried further to give an idea of what can be expected in foundry practice. It is often true, at least I know of several specific instances, that night moulding is so inefficient compared with day moulding that one can practically

double up on melting costs, fixed charges, etc., incident to production on a three shift basis by confining the foundry to one day shift per 24 hours and still gain in production cost.

Under such conditions it is advisable to pour metal only between 7 A. M. and 5 P. M. The steel furnace above referred to has, by starting a furnace crew at midnight, poured two ton heats at 7:30 A. M., 12 M. and 4:30 P. M. with an energy consumption averaging 710 Kw. hrs. per ton. On the same basis of three heats per day, and for copper the furnace would only have to be operated eight or nine hours, the energy consumption on a 12,000 lb. per day output should not exceed 315 Kw. hrs. per ton—the furnace being started cold each morning.

Brass Melting in the Electric Furnace.

If we assume the same furnace efficiency in melting brass that we arrived at for copper, and that assumption is an eminently safe one since melting brass is here the lower temperature operation, we find that we should be able to melt an 80% copper 20% zinc brass in the Weeks furnace as follows:

(1) **Cold Furnace and Cold Charge.**

1 ton brass charge, 530 Kw. hrs. per ton.
2 tons brass charge, 350 Kw. hrs. per ton.

(2) **Hot Furnace and Cold Charge.**

1 ton brass charge, 280 Kw. hrs. per ton.
2 tons brass charge, 205 Kw. hrs. per ton.

(3) **Three Heats Per Day.**
2 ton charges, 265 Kw. hrs. per ton.

It is of general interest, although not of any particular value, to show that the oil burned in an oil fired furnace would if burned in a modern oil engine supply more than enough electrical energy to melt the same amount of metal in the electric furnace.

The theoretical equivalent of 315 Kw. hrs per ton necessary to turn out 12,000 lbs. copper per day is 0.385 gallons oil

per 100 lbs. copper melted as compared with 2.14 to 4.07 gallons used in oil fired furnaces. Practically, 1.24 gallons of oil burned in a modern oil engine would be required to furnish the electrical energy necessary to melt 100 lbs. of copper under the same conditions and this is still much below the oil consumption in the oil fired furnaces.

Discussion.

So far no attempt has been made to get any comparison of fuel costs. With oil at 2.5c per gallon, power on a 3 heat, 12,000 lbs. per day output will have to sell for between 0.40c and 0.82c per Kw. hr. to equal actual costs of oil and blast in oil fired furnaces where energy to the blower is supplied at the very nominal rate of 1c per Kw. hr. and where 1.78 to 3.46 gallons of oil are used in melting 100 lbs. of average red brass.

Even the lower figure, 0.40c Kw. hr. is guaranteed by some of the oil engine concerns selling engines of the capacity necessary to operate a 2-ton furnace, contingent on 2.5c per gallon of just such an oil as was used in our Works. The higher figure, 0.82c per Kw. hr. is obtainable for day loads from a great many of the central power stations in the various cities in this country. The electric melting of brass and copper is therefore on a more attractive basis as regards energy costs than is the electric melting of steel and the latter undoubtedly has a wide commercial application in the making of castings.

As regards losses of metal, the one electric furnace test detailed above does not compare favorably with the figures given for the oil fired furnaces. The loss in the electric furnace should, however, be attributed to seepage into the fresh unglazed lining of the furnace and to more or less skull being left in the furnace since no provision was made for complete drainage of molten metal. In experiments with another type of furnace, which was still less well adapted for copper melting, there was a difference between weight of metal charged (5,000 lbs.) and ingots cast of less than one per cent., and in the latter case there was considerable volatilization of copper— in fact all of the men in the building were seriously poisoned

as a result of the copper fume. In the case of the Weeks Furnace there was absolutely no fume and fume in an electric furnace is really the only possible way of actually losing metal unless slag coverings are used. No slag was used in the Weeks Furnace—merely a shovel full of charcoal covering the metal.

Theoretically, the electric furnace has an immense advantage over the ordinary oil fired furnace in that the electric furnace may be practically sealed to prevent access of air—which means that so long as the vapor pressure of the zinc in the charge does not exceed atmospheric pressure the maximum possible loss of zinc must be the furnace full of zinc vapor.

At the usual pouring temperatures of a 20% zinc brass each cubic foot of gas saturated with zinc vapor contains approximately 0.025 lbs. zinc. In a perfectly closed electric furnace of 150 cu. ft. capacity (Weeks' Furnace capacity), heated uniformly, the maximum loss due to volatilization would be 3.75 lbs. zinc and this would be practically independent of the total amount of brass in the furnace and also independent of the length of time the metal were kept at that temperature. With a 2-ton charge the loss would be 0.094%. Similarly the loss of zinc from a 40% zinc brass at its usual pouring temperature would be somewhere near 0.12%. The loss of copper would be negligable so far as volatilization is concerned in the Weeks or similar furnace.

On the other hand, we have seen that the fuel oil fired furnace requires that some 10,000 cu. ft. of hot combustion products leave the furnace for each 100 lbs. of red brass melted. If these gases left the furnace saturated with zinc at the final pouring temperature they would carry with them many times the amount of zinc originally charged. Fortunately the gases do not by any means all leave the furnace saturated with zinc at the final pouring temperature, not even the gases towards the end of the heat, since with a uniform gas velocity the gas does not remain in the furnace for more than a fraction of a second. But if brass is left in an oil fired furnace under blast after it is ready to come out it does

certainly follow that the zinc percentage in the melt will drop off at an alarming rate.

The same arguments might be used in comparing opportunities for oxidation.

The losses of metal here reported for the oil fired furnaces under test conditions—less than 2%—even if considered all zinc—seem remarkable and are a credit to both furnaces and management. It is folly to claim that the losses in ordinary practice from all sources with the electric furnace would average lower than this 2%, but it is certain that if equally careful crews operate electric furnaces and oil fired furnaces the former will have a decided advantage.

THE ELECTRIC BRASS FURNACE.

We have seen that the use of the electric furnace for melting brass is not at all a commercial impossibility. There are, however, many view points that should be considered by the designer of a furnace for this specific purpose.

In general there are four types of electric furnace, i. e., there are four rather different ways of applying electrical energy to the heating of metals and some of them do at the present stage seem inapplicable.

(a). The Induction Furnace. On account of the high electrical conductivity of the molten copper alloys it has been found difficult to obtain a continuous molten bath without the use of conducting crucibles and at the present time the crucible manufacturers are having a lot of trouble in making an article satisfactory for the purpose.

(b). The direct arc furnaces, in which a slag covering is essential and in which the arcs are drawn to this slag, are undoubtedly the simplest and therefore most attractive.

It has, however, been demonstrated in our own plant that some copper is volatilized in this type of furnace, due to high local temperatures—not perhaps enough to enter seriously into the matter of costs but enough to endanger the health of the workmen unless proper precautions are observed. Slag is

also more or less of a nuisance in the case of the alloys containing zinc. Zinc copper alloys, as has been shown, have high vapor pressures even at their melting points and the margin between pouring temperature and melting point must be made as small as possible to prevent excessive zinc losses and to insure metal remaining quiet in the moulds. This condition makes it imperative that the metal be either poured directly from the furnace into the moulds or that a reasonable heat capacity be provided in the way of hot—not merely warm— ladles. In those foundries with which I am familiar crucibles are provided for the transfer of hot brass to the moulds and these crucibles are always heated in pit furnaces to temperatures well above that of the metal being poured. The managers of these foundries do not consider pouring directly from the furnace into the moulds practicable.

My own experience with tapping furnaces has been unsatisfactory so far as the removal of small portions of a furnace charge of steel and copper are concerned. Pouring over the lip or spout of a tilting furnace, when a slag covering is used, is always more or less accompanied with tedious delays due to the necessity of skimming the metal in the ladles or pots.* If the slag is removed altogether from the furnace before pouring begins then heat can no longer be applied in the direct arc type of furnace and the metal soon gets too cold to pour decently. A satisfactory solution can undoubtedly be worked out but the question of transfer of melted metal must be seriously considered in any design involving this type of furnace as applied to brass castings. Copper has been poured into ingot moulds just as we ordinarily pour steel—through valvular or bottom pour ladles—and the results were quite satisfactory. The ladle must, however, be heated more thoroughly than is ordinarily the case for steel, otherwise nasty skulls are formed.

(c) The Indirect Arc Furnaces such as the Stassano Furnace or such as the Weeks' Furnace herein described, are very simple and the heating is perfectly independent of either slag or

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*Note—It is assumed that bottom pouring from the ladle is impracticable where brass is being cast in green sand moulds.

metal. This is undoubtedly a great advantage. Such a furnace is however quite certain to cost more in repairs to lining, etc., than the direct arc furnace.

The indirect arc furnace as applied to steel has also one advantage (many disadvantages) over the same furnace applied to brass, namely the effect of the presence of intensely hot basic slag on the arc itself. Such a slag promotes the formation and maintenance of a steady arc. Zinc vapor on the other hand is an extremely poor electrical conductor and the arc in a zinc furnace or in a brass melting furnace is snappy and rather unsteady. This is not at all fatal for in Mr. Weeks furnace we kept an arc going for 42 hours continuously in an atmosphere of practically pure zinc vapor. The electrodes were not adjusted once during this period, in fact they were soldered in place, so to speak, by zinc which had condensed and frozen in the electrode openings so that the electrodes could not be adjusted. This condition of unsteadiness of the arc can, however, be remedied to a certain extent by providing suitably designed electrical apparatus. The sticking of the electrodes is also mentioned merely as an incident, that also need occasion no serious worry.

(d). The fourth type of furnace is the resistance furnace in which heat is developed in some portion of the lining, the lining itself acting as resistance or some resistor being imbedded in the lining. Fitzgerald[8] designed an ingenious furnace with a conducting arch or roof from which heat is reflected to the metal underneath and although he[9] referred to it as an unsuccessful furnace it seems to offer possibilities for this rather low temperature class of work. A crucible furnace has been designed in which the crucible serves as resistance. It is said that if an ordinary graphite pot is heated and the graphite allowed to burn out of the inner side of the walls then the clay lining left in the pot is sufficient to keep the metal from seriously short circuiting the crucible resistance. If this is the case the crucible furnace should be useful, particularly for small batches of special metals. In general,

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[8]Trans. Am. Electrochem Soc. XIX 273, 1911.
[9]Trans. Am. Electrochem. Soc. XX 281, 1911.

however, I should personally prefer to work with real and fairly large capacity furnaces.

Finally the furnace heated partly with fuel and finally with current has frequently been proposed. Many have tried to apply this principle but so far as I know no attempt has been very successful. A successful fuel fired furnace must be designed for fuel combustion, and a successful electric furnace must be designed with reference to applying electrical energy simply and efficiently. The two designs have fundamentally different requirements and a furnace designed for the combination is quite certain to be both complicated and inefficient.

On the other hand, while it is perfectly practicable to transfer 5-10 or 20 ton steel heats from a fuel fired furnace to an electric furnace, it seems rather poor economy to transfer small batches, and this would be even more the case with copper zinc alloys. Personally, I should use either a fuel fired furnace or an electric furnace, not both.

<div align="right">

Research Laboratory,

General Electric Co.,

Schenectady. N. Y.
</div>

April 3, 1912.

(Written discussion of this paper is invited, and may be sent to the Secretary, W. M. Corse, care of Lumen Bearing Company, Buffalo, N. Y.)